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Test experiments on muon radiography with emulsion track detectors in Russia

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Abstract

Lebedev Physical Institute (LPI RAS) and Skobeltsyn Institute of Nuclear Physics MSU (SINP MSU) have started the series of test muon radiography experiments in Russia. These experiments are aimed at determination of the optimal conditions of the setup, elaboration of algorithms for data processing and the study of the method peculiarities. The final goal of the method development is drafting of monitoring systems for natural and technological objects which condition may be a threat for the population, infrastructure or environment.

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Keywords: Muon radiography; nuclear emulsion track detectors; monitoring systems

The method of muon radiography is aimed at studying internal structure of massive objects. It is based on measuring of the degree of particle flux absorption in the material of the object under investigation. Atmospheric muons generated by cosmic rays are mostly used as the probing source at the ground level. Both electronic and nuclear emulsion track detectors can serve as registering devices (Carloganu et al. (2013), Ereditato et al. (2011),

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Lesparre et al. (2012), Russo et al.). This work presents our first results of the application of the nuclear emulsion track detectors for study of massive object structure by the method of muon radiography.

Nuclear emulsion was chosen as a muon detector due to a number of its advantages. In addition to the exceptional spatial and angular resolution, it detects charged particles in a wide energy range. Moreover, it is modular and easy in transportation and utilization; large informational capacity allows it to be used in long exposures. Another significant factor in favor of nuclear emulsion is that no electronic readout is required in the experimental setup making it independent on power supply and thus suitable for experiments in hard-to-reach locations.

After the series of preliminary test experiments that allowed to estimate the required exposure time and elaborate the basic data processing algorithms, the first large object was studied with the nuclear emulsion detectors. It was a mine located 30 meters under the ground level with a vertical elevator shaft (diameter of approximately 4 meters) connecting the mine with the surface.

The first goal of the experiment was to register the difference in fluxes of atmospheric muons at the ground level and at the bottom of the mine after their passing through the thick soil layer. For this, several detectors were set on two observation levels - on the ground surface and at the bottom of the mine. The experiment was also aimed at evaluating the possibility of detection of the cavity (elevator shaft) in the soil volume by means of the detector located at a depth of 30 m (Fig. 1a). According to the Monte Carlo simulation (Fig. 1b), the "signal" from the mine shaft should be noticeable in the flux of muons (in the calculations the Y-axis corresponding to azimuth angle Φ=0 was directed to the axis of the shaft, Θ is the zenith angle value).

a b

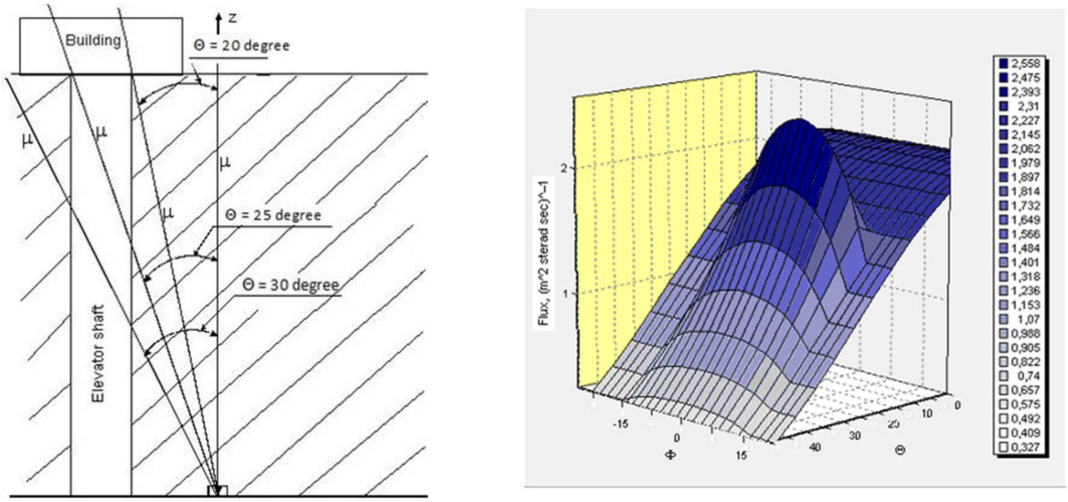

Fig. 1. (a) Scheme of the experiment in the mine shaft at a depth of 30 m; (b) Monte Carlo 3D image of the angular dependence of muon fluxes at the point of detectors' position under the ground. Here the direction Φ = 0 on Y axis corresponds to the position of the shaft.

Here we present the results of this experiment obtained after the exposed nuclear emulsion was processed on high-speed scanning stations in Lebedev Physical Institute and Skobeltsyn Institute of Nuclear Physics MSU. The experimental angular distributions of muons observed in one of the detectors at a depth of 30 m after 4 month exposition are given in Fig. 2. The distribution clearly demonstrates the "signal" from the elevator shaft (indicated by a white framing, Fig. 2a) in coordinates of tx, ty, where $tx=dx/dz=tg(\Theta)\cos(\Phi)$ and $ty=dy/dz= tg(\Theta)\sin(\Phi)$ are tangents of the track inclination angles projected on the planes xz and yz in the frame of the emulsion film. Clear-cut peak is seen in the direction of the elevator mine shaft position at Φ ~ 135° in the coordinate system used in nuclear emulsion film data processing.

The results of a two-month exposure show that the flux of muons in the ground-based and underground detectors differ by a factor of 50: the number of tracks per 30 cm^2 in the detector at the ground level amounted to 31136, while the number of tracks in the detector of the same size at 30 m depth was 671. This result is in agreement with Monte Carlo estimations.

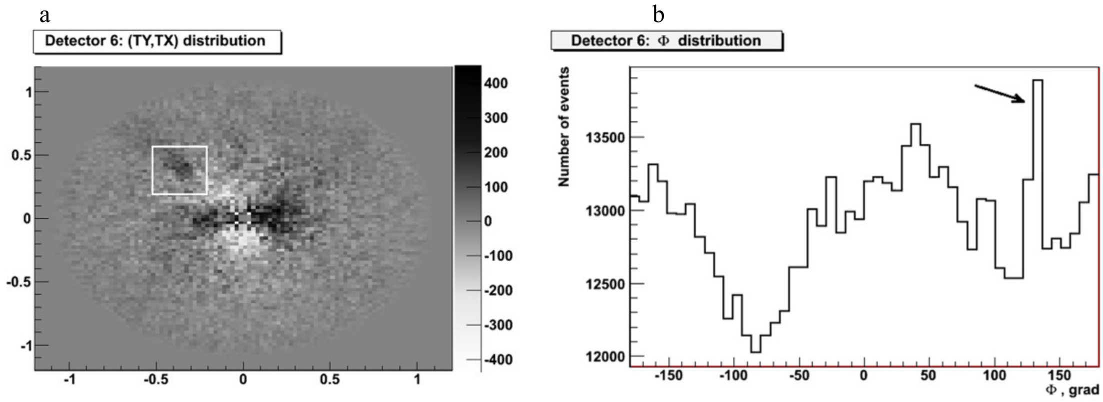

Fig. 2. Muon flux distribution at a depth of 30 m under the ground level (4 month exposition): (a) tx, ty two-dimensional distribution of muon flux at a depth of 30 m; (b) azimuth angle distribution of muon flux at a depth of 30 m. Arrow shows the direction to the elevator shaft.

Conclusions

Analysis of the results obtained in the presented muon radiography experiment carried out by the researchers of LPI RAS and SINP MSU shows that, in accordance with Monte Carlo simulation prediction, the nuclear emulsion technique makes it possible to obtain reliable data on the investigated object structure. Angular distributions of muon fluxes measured in the experiment are in good agreement with the simulation predictions based on the inhomogeneity in the object structure. This suggests that development of the muon radiography method in Russia using nuclear emulsion detectors of the proposed design and emulsion data processing facilities available at the Russian institutes is promising.

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